

Future Directions in Aerospace Technologies

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ABSTRACT

From an assessment of the estimated needs for civil and military aircraft which arise from the predicted future growth of civil aviation and the known needs of the world's defence forces, it is shown that there are compelling reasons for international and inter-company collaboration to meet the demands. From that evidence and two British reports concerning the future of the UK and European aeronautics industry it has been possible to indicate the technology acquisition strategies proposed for future success. Underpinning these strategies are three categories of technology, namely Foundation Enhancing and Supporting. These categories are discussed before presenting a consideration of appropriate aerospace technologies for the future including the propulsion cycle, the use of double fuselage aircraft, the blended wing body concept, the design of long haul subsonic aircraft, new cockpit technology and air traffic management systems.

Keywords: Aerospace technologies, civil aviation, aeronautics

INTRODUCTION

The aerospace industry is world-wide and is important in its use of advanced technology, its need for highly skilled engineering and scientific personnel, its impact on the environment, its military capacity for destruction, its financial demands, its impact on the social habits of every nation, and its safety imperatives. It involves aeronautics, avionics, economics, information technology, legislation, materials science, meteorology, military strategy, and politics. In aeronautics, the concern is wholly with fixed and rotary wing vehicles and with the ground and air support systems such aircraft require to operate. There are special considerations relating to offence and defence for military aircraft. These considerations involve the technologies related to missiles, munitions, communication, navigation, flight guidance and control, life support and electronic counter-measures. The aeronautical concerns for civilian aircraft are more directed to performance and efficiency, profitability and safety. The avionic technology used in such civil aircraft is of the same kind as that employed in military aircraft, but it is used for different purposes. Space activities are carried out to provide global telecommunications and entertainment, for examining the climate and the physical resources of the earth by remote sensing, or for furthering scientific knowledge. The same space technology is used for military purposes: satellite launch vehicles, for example, have been developed from inter-continental ballistic missiles, and satellites can be used for espionage. Both aeronautical and space vehicles operate in controlled environments which need complex and sophisticated operational organizations to function. Not to be involved in aerospace at some level is now virtually impossible for any modern, forward-looking state.

It has been pointed out (AMORIM 1997) that if a developing country cannot gain access to enhanced technology it cannot overcome its economic disadvantages. But the powerful forces of industrial and financial globalization are creating such pressures in the world-wide aerospace industry that existing national aerospace companies face a difficult future without being involved to some degree in international collaboration. Those countries which have no aerospace or supporting educational and training programmes in place will find it increasingly difficult to contribute to future aerospace developments, even if collaboration were possible.

THE GLOBAL NATURE OF THE AEROSPACE INDUSTRY

The world's present population of aircraft consists of the classes shown in Table 1.

TABLE 1
Aircraft population by class

Class of Aircraft	Approximate numbers
General Aviation and Light	250,000
Civilian Transport	18,000
Military Aircraft	25,000
Rotary Wing Aircraft	5,000

The majority of general aviation (g.a.) aircraft are located in the USA. Although product liability laws in that country had a severe effect on the sales of new aircraft, recent legislation has caused the production of such aircraft to resume and remain an American strength. Since reasonable financial returns over development and production costs can only be obtained from large production runs, the aircraft have to be relatively inexpensive and the market large. Such a market exists only in the USA.

The production of military aircraft is subject to political determination, but in the present state of near world peace, military needs are satisfied by USA, CIS, and European aircraft. New combat aircraft such as the EFA, the F22, the JSF are all collaborative venture aircraft. In transport terms, the C-130J, the C-141 and the C-17 are the dominant types; the European FLA has not yet reached a final design. Military helicopters such as the Apache, the Merlin (based on the EH 101) and the Eurocopter Tiger are available and now in service. The largest area of aircraft procurement (in terms of number, if not in value) is in the field of training aircraft. The area of training aircraft is a very considerable one for future world-wide purchases.

In considering civilian aircraft, it needs to be understood that passenger traffic has been growing since 1993 at over 5% per annum. Recent figures from IATA have indicated that airlines anticipate an average passenger traffic growth of about 6.5% per year (even taking into account the recent downturn in the economics of the ASEAN nations) exclusive of charter operations. The annual domestic passenger traffic is still expected to increase from 1.29×10^9 passengers in 1995 to 1.72×10^9 passengers in 2000, while international traffic is expected to grow in the same period from 397×10^6 to 522×10^6 passengers. If a conservative assumption of growth of 5% per year over the next 20 years is assumed, then 18500 new passenger aircraft will be required by 2015 to satisfy that demand (SPARACO 1995). When the costs of the engines, equipment and technical support associated with the acquisition of such a number of aircraft have been added, it is predicted that the market value of these aerospace products over the period will be between \$120 and \$190 billion. Of the total number of aircraft required (10000 additional + 8500 to replace older aircraft), about 5,450 will be wide-bodied, 4,350 single-aisled, 3250 regional jets with a seating capacity of between 50 and 110, and about 5,450 turbo-props (MASEFIELD 1994).

SOME PROBLEMS RELATING TO FUTURE AIRCRAFT PRODUCTION

Turboprops

5,450 aircraft over the period in question corresponds to annual deliveries of 270 aircraft. At present, there are 16 different types available which implies (if market share remains unchanged) an annual production run of 17 aircraft per type. It is not difficult

to deduce that only 7 or 8 of these types will survive through the period and that manufacturers will be compelled to collaborate or go out of business.

Regional Jets

An annual delivery rate of 150 has to be shared between five current types – an average annual delivery rate per type of 30. Unless existing types are replaced, there is no room in the market for a new type. Even with 30 units/year it is doubtful if there is sufficient return on investment to justify continuation of any, but a very few, programmes. In this sector, the number of types must be reduced either by “death” or through collaboration.

Single Aisle Aircraft

With an annual production rate of about 200 aircraft, there remains a fraction of about 50 aircraft per year for other types, if the Airbus A319, A320 and A321 are considered to represent a single family type and the B737 variants are also considered as a single type. In this market sector there appears to be room for only two manufacturers. The future for the new B-717 seems uncertain.

Widebodies

There are at present seven available types, but the recent change in status of McDonnell-Douglas implies that the effective number is 5, with an annual product rate of about 45 aircraft/type. These figures suggest that there is commercial safety for only two manufacturers who are, in fact, already amalgamations of international collaborators.

Regional aircraft are characterized by having low operating costs and relatively low acquisition costs. Airlines require aircraft with the lowest direct operating costs (doc) and the highest earning potential. Seat-kilometre costs rise if the traffic density and number of aircraft seats reduce, and if the block lengths shorten. Either the aircraft purchase cost must be less or the number of seat-kms flown for the same monthly finance charge must rise if the seat-kms cost is to be reduced. To satisfy these demands, either a turbo-prop aircraft, with an acquisition cost of about one-half that of an equivalent-sized jet, or a faster jet, with the prospect of reduced block times, must be chosen. Passengers tend to favour jets on longer routes: the tolerance time for passengers of turboprops is about 90 minutes. In determining d.o.c. the factors shown in Table 2 are representative.

TABLE 2
Breakdown of direct operating costs

Ownership	58%
Fuel	22%
Flight Crew	8%
Maintenance	12%

AERONAUTICAL INDUSTRY IN UK

The UK aerospace industry has a share of the world market of about 10%. Although it exports over 70% of its products it relies upon collaboration, mostly with European partners. Despite this, however, Britain has great concern for the future of its aerospace industry, and that of its European partners, in view of the dedicated main of the US government “to ensure (its) continued leadership in aeronautics”. (US Nat. Science &

Technology Council Paper 1995). In 1992, the Stollery Committee (STOLLERY 1992) considered future plans for developing and maintaining the UK aerospace industry and proposed the creation of a National Strategic Technology Acquisition plan for aeronautics. This plan was based on the following three categories:

- i. Formation technologies defined as those fundamental to the well-being of the UK aeronautics industry;
- ii. Enhancing technologies defined as those which would improve the industry's effectiveness;
- iii. Supporting technologies to sustain the industry.

Examples of the technologies included in these categories are listed in Table 3.

TABLE 3
Technologies in UK National Strategic Technology Acquisition plan

Category One	Systems Integration
	Advanced Wing Design and Manufacture
	Emissions Limitations and Control
	Aircraft and Engine Noise Control
	Low cost Manufacture using fibre composites
	Active Controls and Smart Systems
	Rotary Wing Technologies
Category Two	Advanced Cockpit Technologies
	Health and Usage Monitoring Systems
	Ice Accretion Modelling Techniques
	Real time Data Fusion
	Low Cost Position
	Sensing/reporting Systems
Category Three	Low visibility conditions Sensors
	Design and Manufacture of Smart Systems
	Impact Modelling Techniques
	Knowledge Based Systems
	Safety Critical Software Development
	Integrated Computer Control of
	Design, Development and Manufacture
	Improved Reliability and Maintainability

The UK Government has created a Technology Foresight programme which works ahead for 20 years across 15 industrial sectors, of which aeronautics is one. Foresight presumes that the new technologies which Britain needs to acquire for its future well-being will be detected from perceived market requirements. Such technology acquisition has been considered in the UK to have three main phases:

- pure research;
- strategic and applied research;
- technology demonstration.

Examples of what might be appropriate for consideration as pure and strategic and applied research in aeronautics are presented next.

In defence systems, it requires mathematical modelling, simulation and synthetic environment technologies to model a modern battlefield. These same techniques can be used to study highly complex systems with many interactions which are only imperfectly understood, such as an air transportation system, which is usually taken as comprising

the three elements: aircraft, airports, and air traffic control. These elements are necessary for the safe and economic transport of passengers, baggage, and cargo. World class technological capability in materials, propulsion and aerodynamics are pre requisites for high performance. The ability to produce low weight, high performance, and environmentally acceptable systems relies upon improvements to materials and the associated manufacturing processes for structural and temperature-critical applications. To satisfy the requirements for efficiency, reduced noise and emissions requires advanced engine techniques and aerodynamic design. The Society of British Aircraft Construction (SBAC) has supported three projects which are intended to support this technology acquisition. The projects are:

a. *The Powered Wing*

Here it is intended that the key elements of any wing design for a future large transport aircraft will be integrated. These elements include advanced structures, wing systems, landing gear and powerplants.

b. *Flight Crew Environment*

In this project, avionics are used to achieve the safety, the cost effectiveness and the mission effectiveness of the aircraft.

c. *Ultra Reliable Aircraft*

It is intended by 2010 to have doubled the reliability levels of military aircraft and, in the same period, to have increased the levels of reliability of civil aircraft by at least 50%.

FUTURE AEROSPACE TECHNOLOGY

Aerospace progress was judged in the past by having built larger aircraft that flew faster and higher. Now progress is judged in relation to environmental impact, global competitiveness, and the impact of information technology (I.T.). Although the successful application of I.T. is essential for aerospace activities, its effects are not entirely benign: with the growth of information exchange, electronic shopping, and teleconferencing, there may be a reduced requirement for air travel. Such a possible consequence has acted as an incentive to achieve increased affordability, productivity, and performance from civil aircraft. The emission of NO_x and CO_2 and, especially, water deposition in the troposphere and stratosphere, which results in cloud formation and affects the Earth's radiation "budget", are new and important environmental concerns which have great significance for the choice of propulsion systems for future aircraft. Current open-cycle propulsion systems all produce water vapour; even a switch to hydrogen as a fuel, with its attendant, massive infrastructure costs, would be inappropriate since even more water vapour would be produced. The traditional methods of achieving improved performance by progressive development – even if it could achieve as much as double the present performance figures – are inadequate. An entirely new and different propulsion cycle will need to be found.

There is at present, however, no major effort involving the invention or development or use of long-term advanced technologies – what the UK has considered to be pure research. It has been pointed out by Bushnell (1999) that there do not appear to be available any "magic bullets"; i.e. concepts which have no foreseeable problems, require no research, and provide guaranteed benefits. In attempting to indicate what technological aerospace applications might be useful in future, it will be taken as read that any concept has value only if it works and only if it makes economic or environmental or military sense in the real world: simply being able to do something does not mean that it should be done.

Sub-Sonic Transport Aircraft for Long Haul Operations

Most of the performance gains looked for depend on using Computational Fluid Dynamics (CFD) to achieve effective laminar flow control, vortex and turbulence control and developing the aerodynamic structure to achieve aero-acoustic characteristics which could be classified as anti-noise.

One of the most effective techniques for improving aircraft efficiency is to increase the maximum available lift/drag (L/D) ratio, which is most easily achieved by increasing the span of the wing, reducing the chord, the sweep and the thickness of the wing. There is a limit, however, to the extent of span increase which can be tried because future aircraft must conform to the 80m box * to operate in present day airports without requiring expensive civil engineering modification to the airport environment. Possible maximum L/D ratios of 40 (compared to 18 for a B-747) are theoretically possible, but the structural changes involved require the use of strut bracing. The design problems inherent with obtaining acceptable shock-drag characteristics with such strut braced wings are less acute with the application of numerically efficient CFD techniques. Current aerodynamic techniques are restricted to the use of empirical data because as techniques they are essentially procedures based upon extrapolation and interpolation. With extended span wings with engines at the tip the induced drag can be reduced, in theory, by about 50% if there is circulation control at the empennage region of the aircraft. Thrust vectoring would have to be used to ensure that such strut-braced aircraft could meet the Engine Out conditions laid down in the airworthiness requirements.

Large Double Fuselage Aircraft

To produce an airliner capable of carrying 800 or more passengers, designers are investigating the use of double fuselages joined by a mid-wing section, thus achieving a substantial degree of spanwise load distribution. Since this configuration results in reduced wing bending, there could be a substantial weight savings. By regarding the fuselages as end plates, and the empennages of each fuselage as a winglet, the vorticity from the wings can be made to wrap around the fuselages, thus obtaining the desired laminar flow: using CFD with this approach could be construed as achieving "Designer Fluid Dynamics".

Propulsion for Transport Aircraft

To avoid NO_x and CO_2 emissions, a new and different propulsion cycle is required. One of the most likely solutions is to use an electric motor driving a ducted fan, thereby achieving an energy conversion of about 65% compared to the 30% achieved with gas turbines. The energy needed to power such a propulsion system could be provided from lithium air fuel cells, the effluent from which can be returned for re cycling. The great problem impeding implementation of this scheme is the great weight involved. However, the advantages of conversion efficiency and the electric motor's independence from altitude effects are great potential benefits.

Blended Wing Body Aircraft

The success of the Stealth Bomber, B-2, a prime example of a blended wing body, has encouraged the designers of future large civil airliners to use this planform to avoid the generally accepted disadvantages of large "super-jumbo" aircraft, viz. the noise and vortex hazard. Operating such aircraft would compel considerable spacing of aircraft in

Neither the length of the fuselage nor the span of the wing should exceed 80m

the air traffic control environment, thus reducing the effectiveness of such large aircraft in meeting the predicted increase in passenger traffic. Moreover, the use of such a concept as a blended wing body should lead to an improvement in the L/D ratio achieved and, consequently, reduce the G.T.O.W. and the O.W.E., by virtue of the reduction in wetted area of the fuselage. Such an aircraft type requires the solution of several formidable technical problems, including the need to use thick wing sections, the need to handle the aerodynamic effects of operating with very high Reynolds number, providing adequate stability and control, the achievement of acceptable ride quality, the provision of satisfactory emergency egress for so large a number of passengers, and obtaining compatibility of dimensions with existing airport arrangements.

Cockpit Technology

The use of glass cockpits to provide the necessary display of flight information to pilots is universal in new aircraft, and will be the standard in cockpits for the future. However, new methods of pilot control are very probable. The most likely new forms of pilot input will be speech-based control in which a voice input system will cause an appropriate control action in response to a spoken command. Any Automatic Speech Recognition (ASR) system depends crucially on:

- signal acquisition
- signal processing
- and pattern matching.

For aerospace applications, the key determinant of performance of such a speech recognizer is the Sentence Recognition Rate: isolated word recognition requires a pause of 100 – 250ms between spoken words, which is completely unacceptable for cockpit work. Continuous speech recognition does not require pauses. The vocabulary required would be considered large i.e. involving 1000 – 5000 words.

In military aircraft the microphone is often incorporated in the oxygen mask. The associated transfer function of the microphone dynamics and the acoustic cavity must be such that the frequency response is flat, a necessary requirement for speech recognition. But before pattern matching can take place the speech waveform needs to be transformed into a suitable digital representation. The commonest technique is to use a parallel bank of 10 – 20 band-pass filters with a pass band of 200 – 4kHz. Sampling is normally at a frame rate of 50 – 100Hz. Fourier transforms can be used, but significant improvement in the basic signal representation can be obtained by using a form of Linear Discriminant Analysis (Hunt and Lefebvre 1989).

Pattern matching is invariably carried out by comparing the incoming speech with stored representations which can be phoneme-based, but for aerospace applications, whole word models are best. The simplest method of optimizing the matching is to use Dynamic Time Warping (Rabiner and Juarez 1993) of the sequence of vectors used to represent the incoming speech and the stored word models.

Speech recognizers will always make mistakes. To provide assurance that the spoken command has resulted in the correct action it is necessary, except for the simplest action, for the pilot to be able to monitor the recognizer output, and to have available some method of correcting any perceived errors. The output can be presented visually or aurally. For simple commands no output feedback is needed: if the situation changes, the system has worked. If it doesn't, the command can be repeated. Almost every aspect of continuous speech recognition represents a considerable area of research for the application of this technology to aerospace systems.

The position and the orientation of the head can also be used as a method of interfacing with computers, particularly in the military aerospace environment. The

instrumentation associated with such head tracking is now a relatively mature technology involving in helmet mounted sights, for example, either mechanical linkages or magnetic sensors to provide translation motion and head orientation. Further development of this technology may lead to its application in civil aircraft, and its extensive use in military aircraft to such a degree that a virtual cockpit may be achieved. Although optical head tracking is possible, its use in aircraft is limited, because of its susceptibility to strong sunlight particularly at high altitude, and its proneness to interfere at night with other cockpit systems which use infra-red.

Air Traffic Management (ATM) Systems

An entirely new aerospace market sector is evolving at present and will assume considerable significance in the future: this market sector is satellite-based Air Traffic Management (ATM) systems. Such systems are known as CNS/ATM (Communication, Navigation and Surveillance) or FANS (Future Air Navigation Systems). There are two areas of great technological importance:

- a. the space-based segment which involves the development of a second generation of geostationary navigation satellites to replace the GPS/GLONASS constellation and communication satellites to link ground-based information with the aircraft, and
- b. the corresponding avionic equipment for the aircraft.

It has been estimated by IATA that the cost of providing a basic FANS avionics suite can range from US1 million for a widebody jet to US200000 for a commuter aircraft. Such a suite would allow the aircraft to be connected to the ACARS (Aircraft Communication and Reporting Service) Network and a GPS datalink. Implementation of the Wide Area Augmentation System (WAAS) by FAA is expected in the near future, to be shortly followed by the Local Area Augmentation System (LAAS). An indication of the technology involved in the CNS/ATM market may be gained from a study of Table 4.

CONCLUSIONS

The growth of civilian air travel and the demands for continued military effectiveness in the future require a considerable number of new aircraft. But, in the case of civil

TABLE 4
Satellite-based ATM systems

Function	Segment	Equipment
Communications	Airborne	FMS, FANS-1 Equipment, AMSS Voice/Data, VHF/HF Voice/Data receivers, Mode-S transponders, ADS, Satcom Antennas, GNSS, ARINC databases.
	Ground-based	VHF digital radio for voice/data. Satcom ground sta. CPDLC workstations, ATN/AMSS data/voice FTPS, RDPS, ATIS, weather systems.
Navigation and	Airborne	GPS/GLONASS, INS, baro. altimetry, MMR, DGPS, EGPWS.
	Ground-based	Satcom Gnd. Stn Integrity monitoring, GLS, differential ground stations.
Surveillance	Airborne	ADS, CDIT, ACAS/TCAS
	Ground-based	Mode S, Signal Processors, displays & HMI tools.

aircraft, the need to achieve the best economic performance without further damage to the environment and, in the case of military aircraft, the need to provide superior performance for offence and defence at affordable cost, require the application of new technologies. Developing such technologies, and producing such aircraft, however, will require technical, financial and scientific resources far beyond the capacity of any single aeronautical company, so that such work in the future must involve international and inter-company collaboration to an even more marked degree than today.

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